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Petrol Filling Stations as Emerging Social Hubs: Assessing Health Risks and Urban Planning Challenges – A Case Study of New Cairo, Egypt

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Nanees Abd El-Hamid Elsayyad [1]

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Abstract: The relationship between urban planning, public health, and the risks associated with petrol filling stations (PFS) serving as informal social hubs is increasingly significant in rapidly urbanizing areas. In New Cairo, Egypt, PFS have evolved from purely service-oriented spaces to vibrant social gathering points, a trend that became more prominent during the COVID-19 pandemic. This shift demonstrates how urban infrastructure adapts to changing societal behaviours but also introduces public health concerns, including increased exposure to volatile organic compounds (VOCs) and a heightened risk of disease transmission. This study aims to assess the dual role of PFS as both essential urban facilities and emerging social spaces, examining their health and environmental implications. A mixed-methods approach, including a literature review, behavioural analysis, spatial assessments, and structured user surveys, is employed to evaluate VOC exposure levels, social interaction patterns, and public risk perceptions. The findings reveal that PFS function as critical social nodes, particularly for young adults. However, air quality measurements indicate that VOC concentrations near seating and gathering areas often exceed WHO-recommended safety thresholds. The research underscores the need for integrated urban planning and public health policies that balance the social utility of PFS with necessary safety regulations, ensuring healthier and more sustainable urban environments.

1. Introduction

Pandemics have significantly altered the relationship between people and cities, with negative and positive societal implications for how people interact with urban places. Public spaces have assumed a crucial role in addressing urban challenges and meeting human needs within cities. Mediated spaces, in particular, are highly recommended by researchers in urban public space designs as they encompass diverse activities that promote users' feelings of security, enjoyment, belonging, and overall well-being (Trigg, 2017). Unconventional spaces, such as petrol filling stations (PFS), are increasingly used as informal gathering spots, especially in urban areas with limited public spaces (Csambalik et al., 2024). Recent research highlights the need for IoT-enabled

[1] Assoc. prof., Architectural Engineering, Engineering Faculty, Mansoura University,Egypt. Nanees_elsayyad@mans.edu.eg

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sensors and AI-based monitoring systems to manage these risks effectively and ensure healthier environments (Popescu et al., 2024). The concept of a petrol filling station (PFS) as a public space has gained prominence, primarily due to its open and non-gated nature, making it conducive to use, especially during the pandemic. It has become an integral part of the urban lifestyle, persisting from the pandemic to the present.

However, it is essential to note that (PFS) comes with various hazards, as Burton et al. (1978) outlined (McNamara et al., 2020). These hazards encompass physical environments that threaten human well-being, livelihoods, property, and the environment. They can cause harm in the form of injury, disease, economic loss, and environmental damage, including pollution and the loss of natural resources and amenities (Muketha et al., 2019). During delivery, storage, and fuel dispensing at (PFS) stations, unburned fuel can be released to the environment in either liquid or vapor form. Fuel is a complex mixture of chemicals, both toxic and carcinogenic. So, the health consequences of chronic benzene exposure are best understood (Hilpert et al., 2015).

Petrol filling stations (PFS) are emission sources of volatile organic compounds (VOCs), which have been the subject of considerable research and environmental studies to evaluate the associated air quality (Baeza Caracena et al., 2010). One of the environmental impacts caused by the activities of (PFS) is the effects caused by fires, which, when they occur, are very harmful to employees, customers, owners, and the neighborhood and may cause fatalities. According to (de Albuquerque Azevedo and de Souza Bias, 2011) . Furthermore, (PFS) has an impact on health, where numerous studies have demonstrated that exposure for one minute/ day during refueling (>3000 μg/m3) results in very high concentrations of benzene in the blood. This is a significant concern for residents and users nearby and frequenting the area because inhalation is the predominant route of human exposure to benzene. To reduce the effects of this symptom, the World Health Organization has recommended an annual air quality benzene exposure limit of 5 μg/m3 (Manini et al., 2008)

Petrol filling stations (PFS) are integral components of the built environment and are commonly dispersed throughout communities. Consequently, the operation of (PFS) can present opportunities for various individuals to be exposed to fumes when filling the station's tanks and refueling vehicles (Hilpert et al., 2015).

2 Literature Review

2.1 Public Urban Space and Social Interactions

There are numerous definitions of open spaces or public open spaces, and we cannot agree on a single definition encompassing them all. However, for clarity, we will define open (public) urban spaces as places or areas to which the public has visible or physical access (El Khateeb and Shawket, 2022). According to (Carr, 1992), an urban space is a "publicly accessible place where people go for group or individual activities." It is crucial to consider accommodating a range of social behaviours when defining public space and its accessibility to the general public. In 2009, Loukaitou-Sideris, A., & Ehrenfeucht, R. defined it as “a public space that fosters public use, active or passive social behaviours, and where people are subject to the general principles that manage the use of the space” (Fahmy, 2018). (Fishman, 1990) likened modern cities with pervasive car use to a "city à la carte." Just as customers choose their dishes at a restaurant, they can also freely select their routes and stops. Given this, visiting the PFS is typically only one stop in a more comprehensive individual (or group) experience (Khahro et al., 2014).

Public spaces play a critical role in urban settings by fostering social interactions and promoting well-being. However, these spaces pose risks during pandemics, as their design and density can impact public health. Urban populations increasingly utilize unconventional social spaces such as petrol filling stations (PFS).

2.1.1 Marc Augé's Non-Places Theory

The term "non-place" was introduced by French anthropologist Marc Augé in his 1995 work, "Non-Places: Introduction to an Anthropology of Supermodernity." He defines non-places as transient spaces that lack the relational, historical, and identity-based attributes typically associated with places. Examples include airports, shopping malls, and motorways—spaces designed for functionality and movement rather than fostering social connections or cultural significance. (Üngür, 2019) (Marc and MACKIAN, 1995). Non-places," according to Marc Augé, are zones between moments of arrival and departure, serving as transition points rather than having a distinct purpose. People typically do not feel a strong connection to these areas because they are more like transitions between two moments or two locations rather than actual physical places. Thus, any location lacking a clear identity, historical context, or a web of interconnected relationships is labeled a "non-place." This concept exemplifies the characteristics of our era, influenced by an excessive embrace of modernity (Giovannoni, 2016).

Marc Augé's disconnection is linked to his generation. However, younger generations, such as today's youth, might regard places like train stations as places to store their history, identity, and social connections. Nevertheless, Augé acknowledges that traditional places and transitional non-places coexist and can potentially transition into one another. PFS is hardly ever regarded as a public area. However, these areas enhance social interactions by offering coffee shops, restaurants, pastry shops, newsstands, stores, and food vendors. These activities are readily available with ample parking and are frequently open around the clock in a nation that closes early. Consequently, PFS has evolved into hubs for various social interactions, particularly among young people (though not exclusively) (Giovannoni, 2016).

2.1.2 Petrol Filling Stations as Emerging Social Spaces

Petrol filling stations (PFS) are facilities where fuels like gasoline are sold, often accompanied by services such as car washes, convenience stores, and food outlets. Traditionally, PFSs have been viewed as "non-places," coined by anthropologist Marc Augé to describe transient spaces lacking significant social or cultural value. However, recent observations indicate that PFSs are evolving into social hubs, fostering interactions among patrons. This transformation is attributed to their 24/7 operation, diverse services, and strategic locations, encouraging customers to engage beyond refueling (Albatayneh et al., 2024). Despite this shift, PFSs are rarely designed with public life in mind, presenting challenges in urban planning and design. Recognizing PFSs as emerging social spaces necessitates reevaluating their role in urban environments, emphasizing the need for designs that enhance social engagement while ensuring safety and functionality (Giovannoni, 2016).

2.2 Health and Environmental Risks Near Petrol

Exposure to benzene at petrol stations poses significant health risks, as numerous studies have established a link between proximity to these facilities and an increased incidence of various cancers. Vulnerable populations such as children are particularly at risk; research by (Malavolti et al., 2023) found that children living within 50 meters of a petrol station have a 2.9-fold increased risk of developing acute lymphoblastic leukemia. Complementary findings from (Mazzei et al., 2022) and a meta-analysis by further substantiate the heightened risk of childhood cancers associated with benzene exposure near petrol stations.

Additionally, benzene exposure has been associated with an array of other cancers, including leukemia, lung, stomach, and kidney cancers. (DeMoulin et al., 2024) reported that benzene levels exceeding 550 mg/m³ significantly increase leukemia risk among workers (aHR=2.3). Chronic exposure also leads to serious respiratory conditions and haematological alterations, impacting blood health and overall well-being (Binsaleh et al., 2024).

Further supporting these concerns, a systematic review in the "Journal of Environmental Health" emphasized the link between proximity to petrol stations and higher risks of respiratory and skin diseases, recommending the establishment of buffer zones to protect public health .This review also noted significant variations in oil leakage based on distance from residential areas, with substantial leakages within 25 meters of petrol stations, raising concerns about fire risks and property damage.

A study from South Korea highlighted environmental concerns, reporting median outdoor benzene concentrations of 9.9 µg/m³ within 30 meters of gas stations, which decreased to 6.0 µg/m³ at distances of 60-100 meters. Indoor levels were considerably higher, and investigations into oil leaks revealed considerable pollution within 25 meters of gas stations, suggesting potential property damage and fire hazards. (Fontes et al., 2016). Research spanning several decades has consistently shown that workers in petrol filling stations (PFS), who are chronically exposed to these environments, suffer from a range of health effects including eye and skin irritation, dermatitis, leukemia, and genetic mutations. According to de Araujo et al. (2023), the pathways of human exposure to these health risks include skin contact, inhalation of vapours, and the consumption of contaminated water. These studies underscore the urgent need to address health and safety concerns for individuals working in or residing near PFS, highlighting the complex interplay between environmental pollutants and health risks associated with proximity to petrol stations. (de Araujo et al., 2023),

Table 1: Health and Pollution near Petrol Stations", (source: Author according to previous sources)

Distance from Petrol Station (meters)	Percentage of Oil Leakages	Health Effect Type	Specific Symptom(s)	VOC Compound(s) Involved
0 - 25	22.13%	Short-Term	Respiratory Irritation, Eye/Nose/Throat Irritation, Headaches, Dizziness	General VOCs, Benzene
25 - 50	17.45%	Long-Term	Liver and Kidney Damage, CNS Effects, Cancer Risk	Benzene, Toluene
50 - 75	8.33%	Reduced Impact	Minor or no direct reports	Lower concentrations of VOCs
75 - 100	3.91%	Minimal Direct Reports	Minor or no direct reports	Lower concentrations of VOCs

2.3 Health and Environmental Impacts of Petrol Stations as Social Spaces

Based on the previous literature review, utilizing petrol filling stations (PFS) as social spaces presents benefits and challenges. PFS can provide convenient gathering spots that enhance community interaction and accessible venues for quick meetings or social check-ins (Leary et al., 2024). Negatively, these areas expose visitors to harmful pollutants like benzene, leading to significant health issues such as respiratory problems and long-term effects on the central nervous system (Saeedi et al., 2024). The dual role of PFS underscores the importance of balancing community benefits with health and environmental risks, advocating for improved safety measures at such multifunctional sites. These impacts are summarized in (Table 2).

Table 2: Positive and Negative Aspects of PFS Use as Social Spaces
Source: Author according to (Nasution and Zahrah, 2012), (de Albuquerque Azevedo and de Souza Bias, 2011)

Positive	aspects	Negative	aspects
Amenities	The station is a comfortable place to hang out because it has standard amenities like seating areas, Wi-Fi, and clean restrooms.	**Air quality**	Gasoline and other fuels emit fumes, which can cause air pollution and aggravate cardiovascular and respiratory conditions.
Food and drinks	The station's wide selection of food and beverage options may draw visitors and encourage them to stay.	**Soil and water pollution**	Soil surrounding a PFS may become contaminated with gasoline, which contains the toxic chemical benzene and can leach into the water supply.
Increased social interactions	Communities can be strengthened, and social interaction can be heightened by using a social PFS as a meeting point for the local population.	**annoyance** **Light pollution**	Petrol stations' bright lights, particularly at night, can interfere with sleep cycles and harm the local population's health.
Improved local economy	A social fuel station may also strengthen the local economy by drawing consumers who might spend money and time on food, drinks, and other amenities.	**Noise pollution**	People who live nearby may experience hearing damage or disturbances to their quiet due to the noise produced by traffic and other activities at PFS.
Reduced crime	An active, well-lit PFS can reduce crime in the neighborhood and make it a safer place for locals to live.	**Traffic congestion**	Elevated traffic around petrol filling stations, mainly when they serve as social hubs, can result in traffic congestion and greater exposure to air pollution caused by vehicular emissions.
Increased business opportunities	A community-focused PFS has the potential to draw in customers from the surrounding area, thereby creating more business opportunities for nearby shops and businesses. Marketing and promotion.	**Fire Risk**	This is because, even at very low temperatures, petrol emits highly flammable vapors that can ignite if they meet a heat source. An electrical switch, a cigarette, or a static electrical discharge is all potential sources of ignition sparks.

According to the previous table, to achieve positive aspects and avoid negative aspects for PFS, a methodology that relies on two key axes should be followed to transform petrol filling stations into sustainable social hubs, as illustrated in Fig 1). These axes are enhancing environmental quality and life quality within these stations. Environmental quality involves factors such as thermal comfort, air quality, lighting levels, and noise reduction. Life quality is assessed through objective and subjective standards. Working on these axes helps develop high-quality public spaces that provide comfort, connectivity, and protection, thus making these stations sustainable social centres

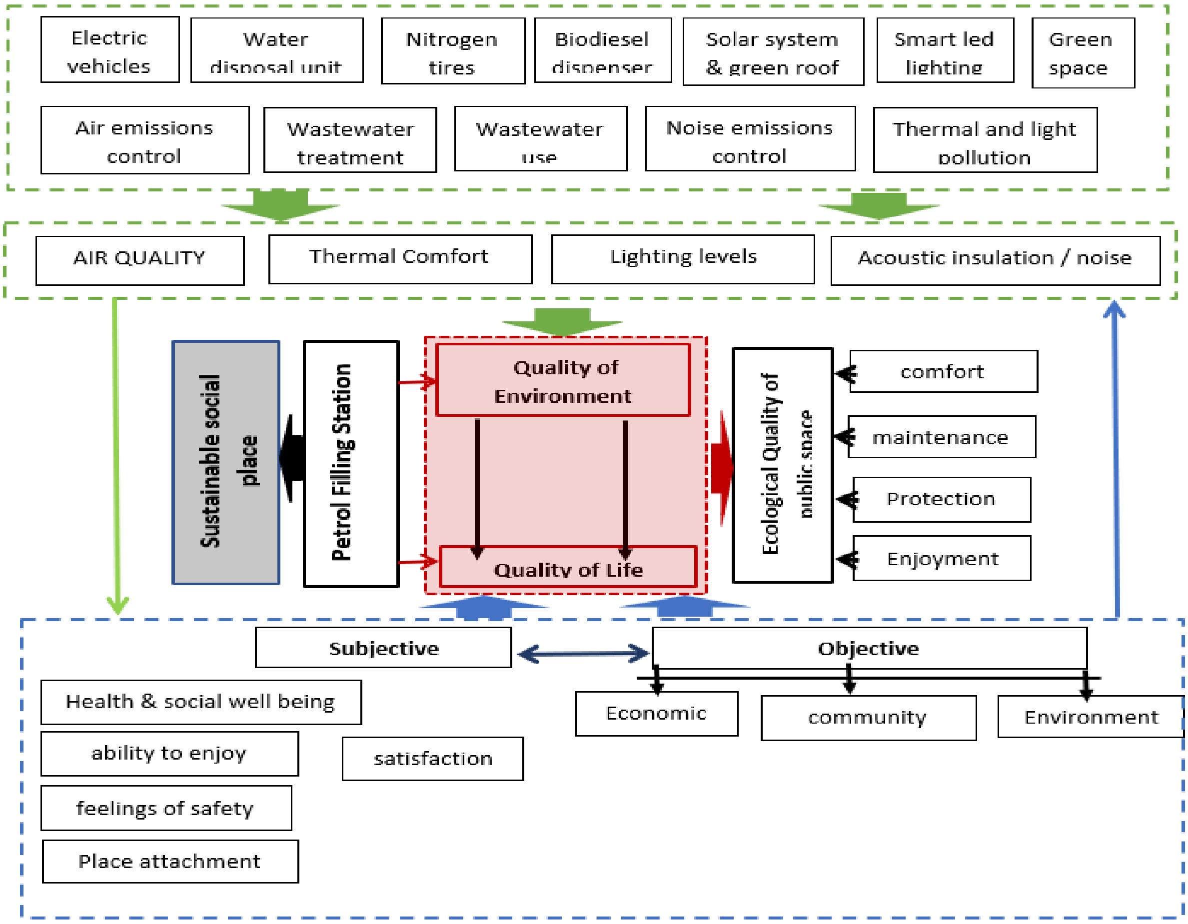


Fig. 1: Sustainable Framework for PFS. Source: Author

2.4 Global Practice for Mitigating Health and Environmental Risks at Petrol Filling Stations.

As petrol filling stations (PFS) increasingly function as fueling points and informal social spaces, urban planners worldwide have implemented strategic policies to mitigate the associated health, environmental, and urban planning risks. These global trends focus on reducing VOC exposure, improving air quality, and ensuring safer urban spaces through zoning regulations, green infrastructure, VOC monitoring, public awareness campaigns, and alternative social hubs.

In Germany and the Netherlands, the implementation of 75-meter buffer zones around fuel dispensers serves as a strategic measure to mitigate VOC exposure and its associated health risks. These regulations are designed to minimize harmful compounds such as benzene and toluene, which contribute to respiratory issues and long-term illnesses, including cancer (Alenezi and Aldaihan, 2019). Research indicates that proximity to fuel stations significantly increases indoor and outdoor VOC concentrations, highlighting the necessity of stringent environmental controls. Similarly, in the agricultural sector, buffer zones have proven effective in reducing exposure to hazardous emissions, as seen in their application to mitigate spray drift from nozzles (Herbst, 1998). While these measures help protect public health and improve air quality, they also pose operational challenges, requiring a careful balance between regulatory compliance and economic viability.

In Sweden, the government has implemented mandatory eco-labelling on fuel dispensers since October 1, 2021, to provide consumers with information about the climate intensity, renewable share, and origin of transportation fuels. While this initiative primarily focuses on environmental impact, it indirectly raises public awareness regarding fuel emissions and sustainability (Mobilister, 2021). Paris and Seoul have undertaken significant urban redesigns to reduce dependency on petrol filling stations

(PFS) and promote alternative social spaces. In Paris, the city government has transformed approximately 60 hectares of public space by converting 70,000 parking spots into pedestrian-friendly areas, electric vehicle (EV) charging stations, bicycle parking, and green zones. This initiative aims to reclaim 85 kilometres of roads previously dominated by vehicles, enhancing walkability and community engagement.
Similarly, Seoul has aggressively expanded its EV infrastructure, increasing the number of charging stations from 8,387 at the end of 2020 to over 35,000 by September 2022. This expansion supports the integration of emission-free zones and encourages the adoption of electric vehicles, contributing to cleaner urban environments and offering residents safer, more sustainable social spaces. These efforts by both cities exemplify proactive strategies to reduce reliance on traditional fuel sources and foster healthier, more vibrant urban communities. ((ITDP), 2023) (Government, 2022). California enforces strict VOC monitoring at fuel stations through the Air Resources Board (CARB), which mandates certified vapor recovery systems to capture emissions during fuel storage and transfer. These systems undergo regular testing to ensure compliance with emission standards ((SDAPCD), 2024). In Canada, Environment and Climate Change Canada (ECCC) has introduced regulations to reduce VOC emissions from petroleum storage and loading, aiming to cut fugitive VOC emissions by 494 kilotons’ and methane emissions by 8 kilotons’ between 2024 and 2045 (Gazette, 2024). Both jurisdictions emphasize rigorous monitoring and regulatory enforcement to improve air quality.

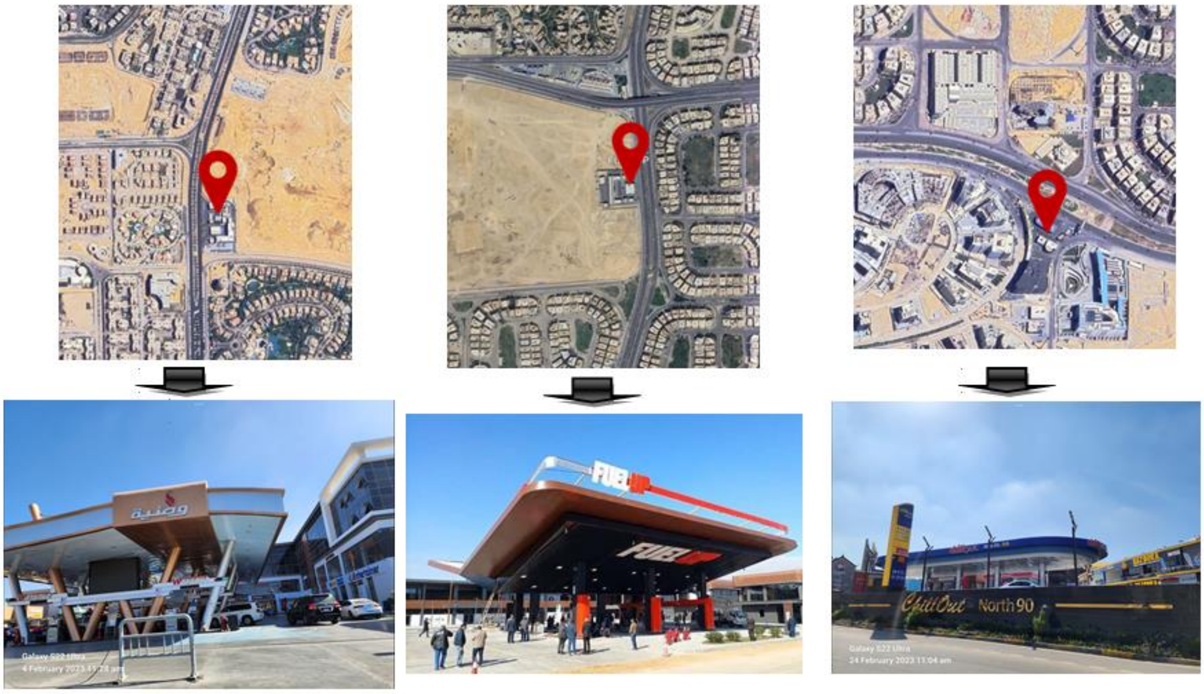
3. Study Area Overview

The increasing population in New Cairo and a growing reliance on automobiles and other transport means have led to a noticeable rise in the city's construction of petrol filling stations (PFS). These stations have evolved their design concepts to meet the changing needs of the local community, expanding their offerings beyond traditional fuel services. This adaptability has become particularly crucial in the post-COVID-19 era, positioning PFS as valuable social spaces amidst a shortage of public gathering areas. Figures 2, 3, and 4 illustrate the spatial distribution of the selected petrol filling stations in New Cairo. The study utilized a random sampling method, choosing stations based on their urban location, accessibility, operating hours, and capacity to act as social hubs. Observations for the study began in July 2023, adopting a long-term perspective. This approach included examining:

- The social dynamics of the PFS at various times across the week.
- The relationship between the stations and their surrounding neighborhoods, both spatially and socially.
- The demographic profile of the patrons frequenting these stations, noting their characteristics and numbers.

Fig. 2: New Cairo map.
https://sakan.com.eg/real-estate/new-cairo-

Fig. 3: Location of selected petrol filling station in New Cairo 1 Google Earth



Station 1:Watany	Station 2: Full Up New Cairo 1	Station 3: Chill Out North 90, New Cairo 1
Area/m2 16.160 m²	13.706m²	12.05m²

Fig. 4: Characteristics of selected petrol filling station in New Cairo 1
Google Earth Source: Google Earth

3.1 Methodology for Study Area Analysis

This study's methodology combines systematic observations, data collection, and analytical techniques to assess VOC levels and their potential health impacts near petrol filling stations. Through careful selection, each stage in the methodology aims to comprehensively understand the environmental and social dynamics within the study area.

3.1.1 Stages of methodology:

The methodology for this research can be broken down into several stages:

- **Observatio**n: This stage involves the initial observations of the petrol filling stations (PFSs) and their surroundings, including users arriving on foot and by car, the variations in activity throughout the week, and the most common areas used in them.
- **Social Evaluation:** The research used a questionnaire to evaluate the PFS as a social place. This questionnaire likely covers aspects of social interaction and activities near the PFS.
- **Evaluation of Air Quality:** In this step, the research assesses air quality in different areas at PFS by using a specific device (D9) to measure air quality at various zones at PFS.
- **Data Analysis and Interpretation:** The collected data were analyzed to explore the correlation between proximity to petrol pumps, VOC concentration levels, and visitor frequency in each designated zone. According to WHO (Organization, 2010)Statistical analyses were applied to identify significant differences in VOC exposure across various zones and examine the relationship between VOC levels and their impact on health. This analysis includes VOC levels and corresponding health risk categories associated with each zone's distance from the petrol filling station (as shown in Fig. 5).
- *Zone* 0 (0–25 m): Hazardous with VOC levels around 15 μg/m³

- *Zone* 1 (25–50 m): Very Unhealthy with VOC levels around ten µg/m³
- *Zone* 2 (50–75 m): Unhealthy with VOC levels around seven µg/m³
- Zone 3 (75–100 m): Acceptable with VOC levels around five µg/m³

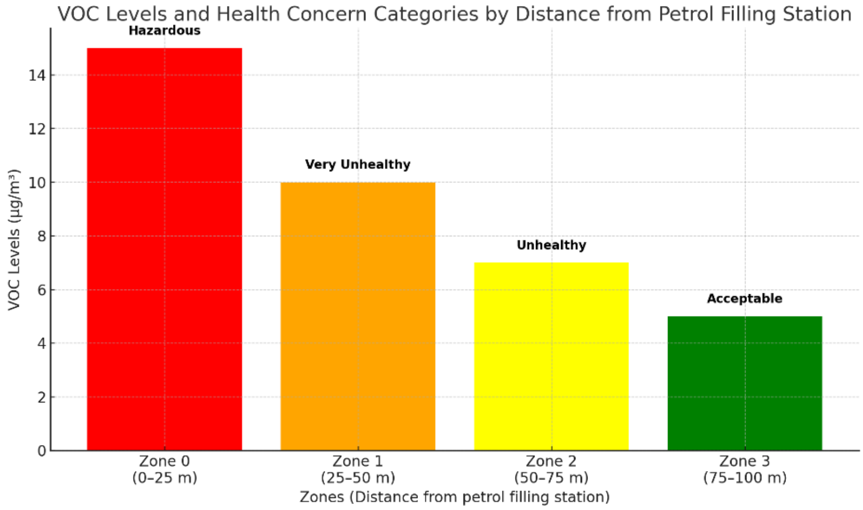


Fig. 5: WHO Health Risk Categories by VOC Levels near Petrol Stations"

Source: Author According to (the World Health Organization, 2022. Guidelines for indoor air quality: Selected pollutants. Available at: https://www.who.int/publications/i/item/9789289002134& scientific researches

Stage 1: observation.

The research examines the interplay between petrol filling stations (PFS) and their urban surroundings. These (PFSs) are strategically located on roads for easy vehicle access. The study's primary focus is to investigate how frequently (PFS) is used by locals by observing the number of pedestrians, nearby residents, or regular visitors who rely on them.

The research reveals that during the weekdays, these stations are relatively quiet in the morning, mainly serving commuters. However, they experience higher traffic on weekends and during peak seasons, indicating increased social activity in some (PFS), possibly with amenities like cafes or spaces that encourage social interactions among people. Petrol filling stations (PFS) have established a notable social bond with their environment. It is essential to differentiate between their spatial and social relationships with the neighbourhood. Regarding physical proximity, these stations are somewhat disconnected, situated on the neighbourhood's outskirts, and often difficult to access on foot. However, their social connection to the neighbourhood appears substantial, particularly among the younger population. Additionally, these PFSs serve as a crucial nighttime social hub, often being the only open establishment during late hours. The social life at petrol filling stations (PFS) becomes more vibrant during specific times, notably during lunchtime, in the afternoon, and at night, especially on weekends.

Stage 2: Social Evaluation

A survey was conducted among users of the petrol filling station, which is regarded as a social hub, and (57) individuals participated in the questionnaire while at the station. Upon analysing the survey results, the following key findings emerged: (74.1%) of the station's users fall within the young adult age group, ranging from 18 to 30 and (14.8%) are under the age of 18. The majority of users originate from different cities.

PFS are easily accessible, both by car and on foot, as they offer daily services. The findings indicate that 22.2% of visitors frequent these stations for dining and socializing, especially on Thursdays, Fridays, and during the summer, as shown in (Figs 6 &7). These stations are considered vibrant and active places for social interactions, contributing to user satisfaction. Despite their limited green spaces and modest weather protection, petrol stations are well-designed with adequate lighting. Users often feel secure at these locations, even though they know the potential risks associated with the stations' impact on themselves and the environment. The following (Table 3) illustrates the results of the questionnaire analysis:

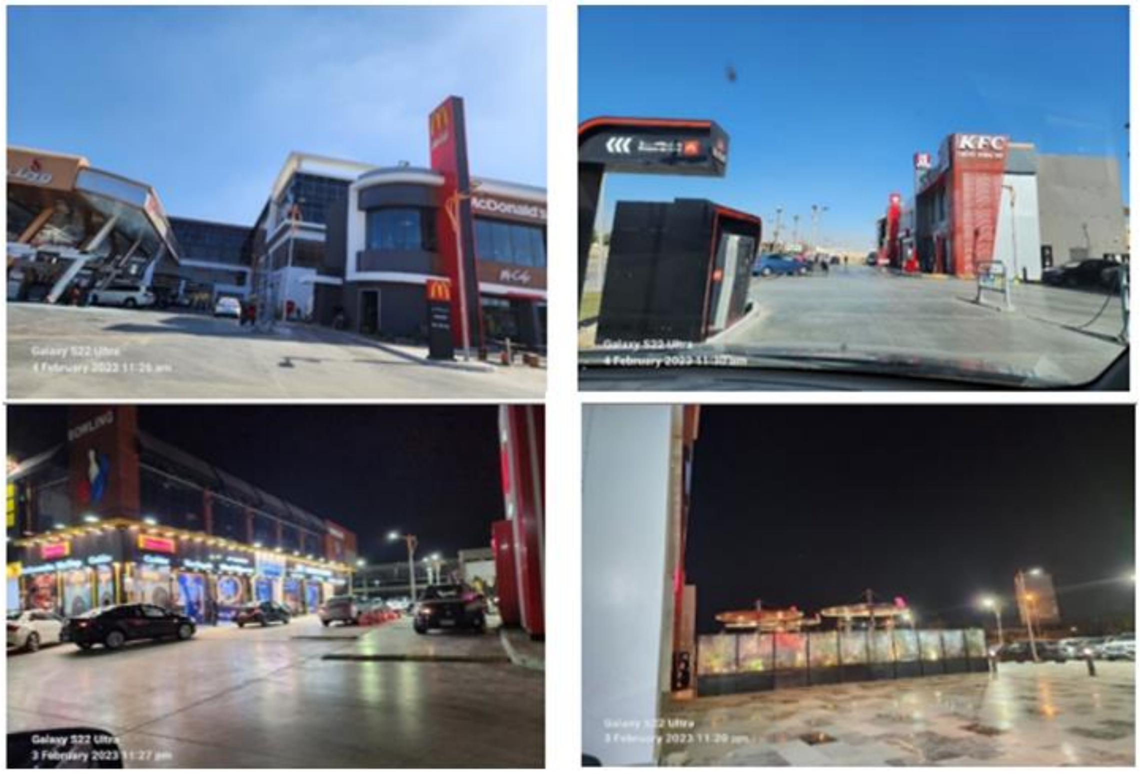
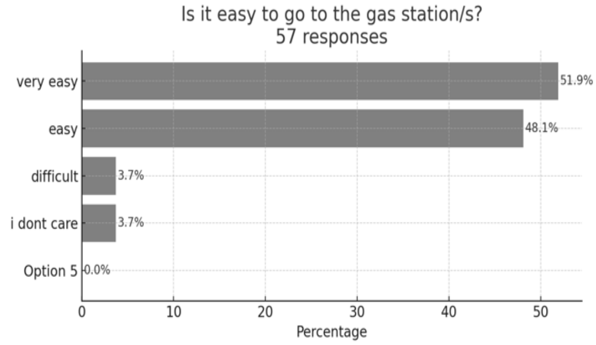
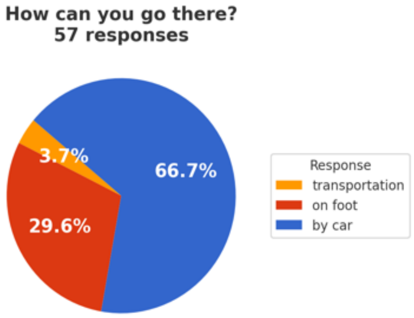


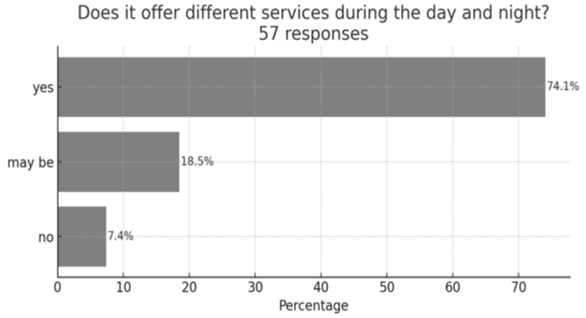
Fig.6: Social life at Wataniya PES in the morning and at midweek Source: Author

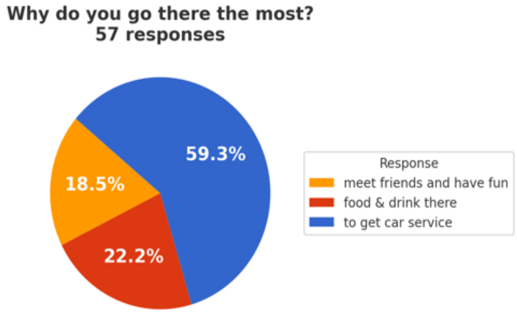
Fig. 7: Social life at Wataniya PES at the weekend Source: Author

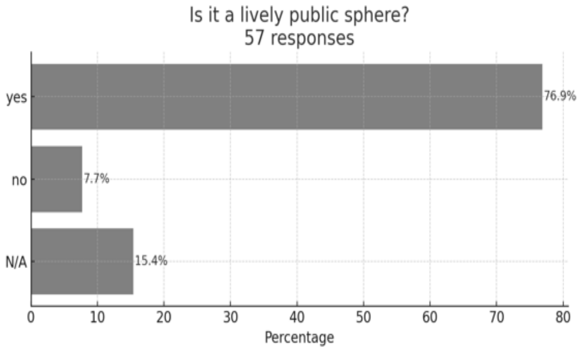
Table 3: Key Findings from Questionnaire Analysis", Source: Author

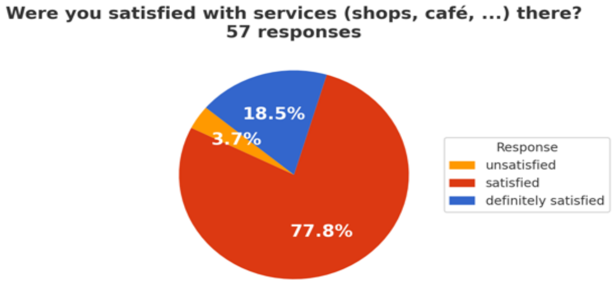


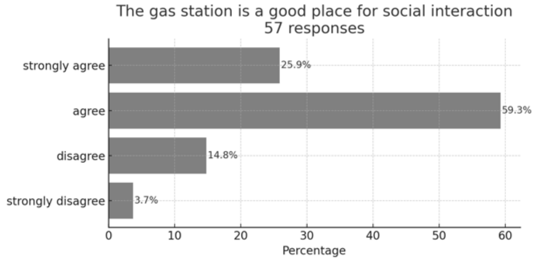


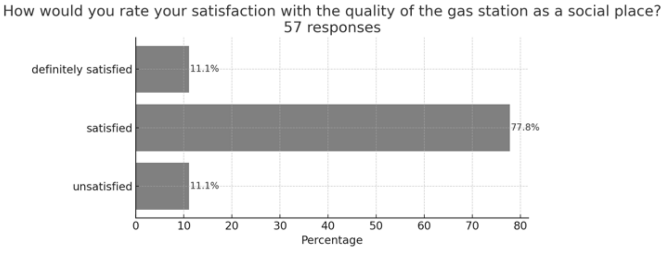


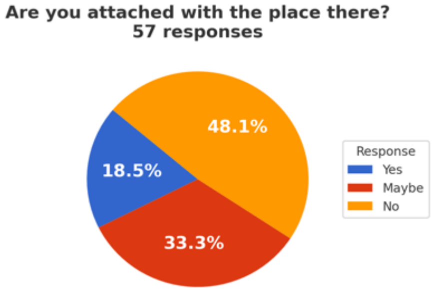


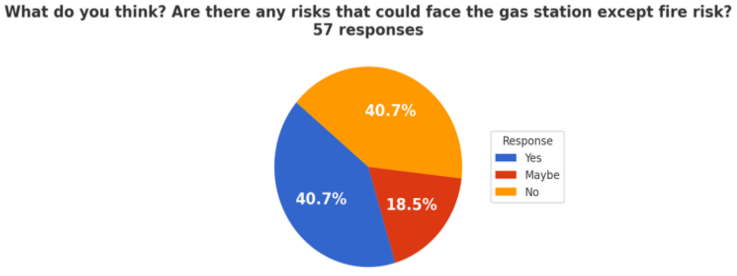


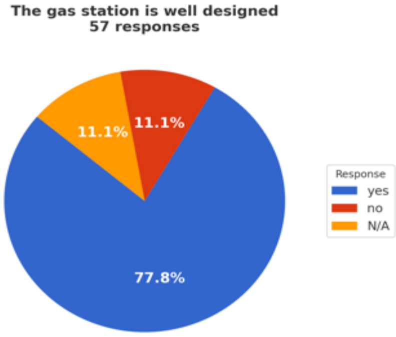


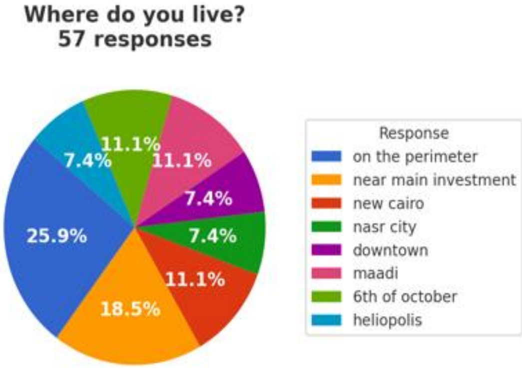


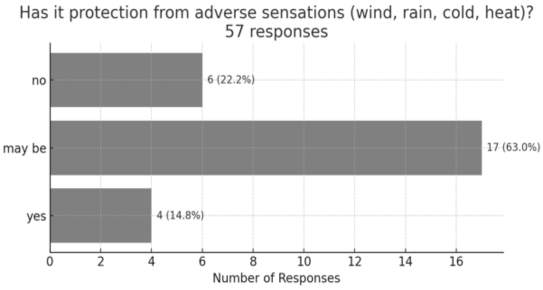


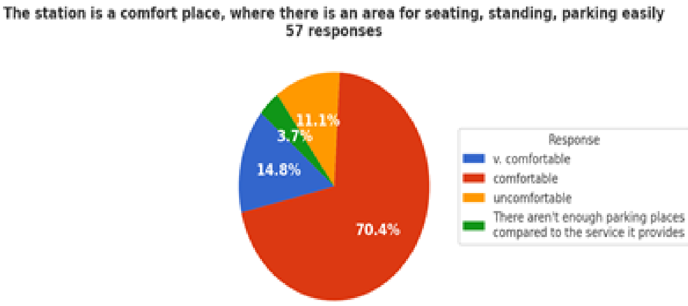


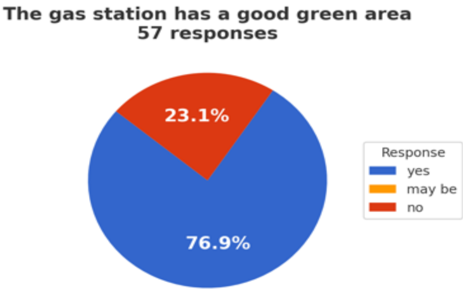


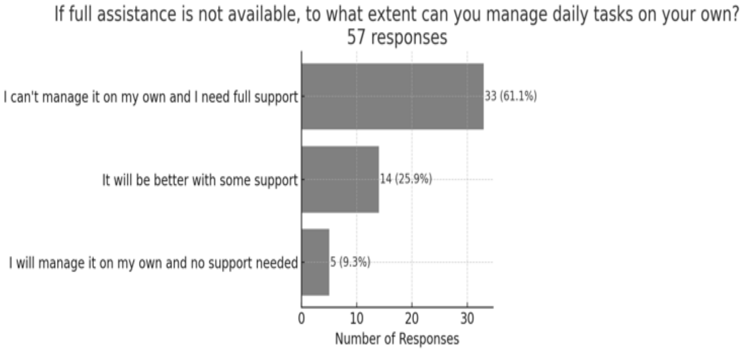

The gas station is well designed
57 responses
11.1%
11.1%
77.8%
Response
yes
no
N/A

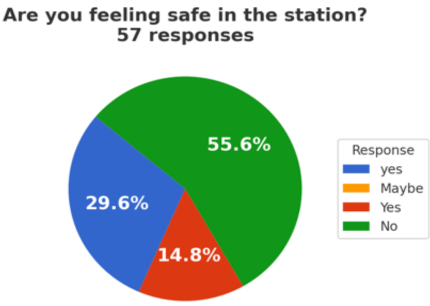

Where do you live?
57 responses
7.4%
11.1%
11.1%
7.4%
7.4%
25.9%
11.1%
18.5%
Response
on the perimeter
near main investment
new cairo
nasr city
downtown
maadi
6th of october
heliopolis

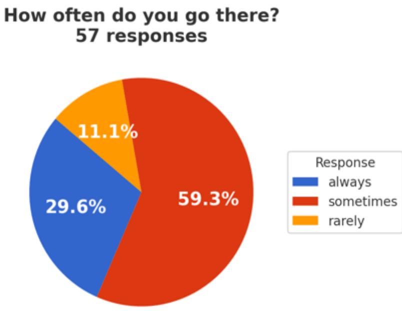

Has it protection from adverse sensations (wind, rain, cold, heat)?
57 responses
no
may be
yes
6 (22.2%)
17 (63.0%)
4 (14.8%)
0
2
4
6
8
10
12
14
16
Number of Responses

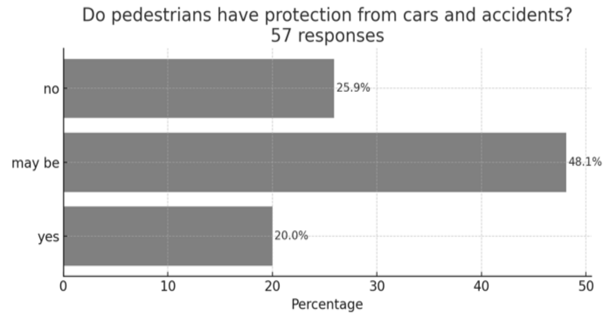

The station is a comfort place, where there is an area for seating, standing, parking easily
57 responses
11.1%
3.7%
14.8%
70.4%
Response
v. comfortable
comfortable
uncomfortable
There aren't enough parking places compared to the service it provides

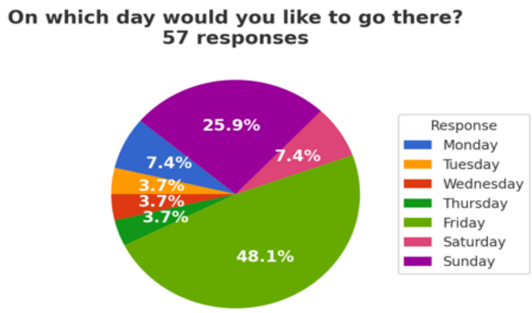

The gas station has a good green area
57 responses
23.1%
76.9%
Response
yes
may be
no

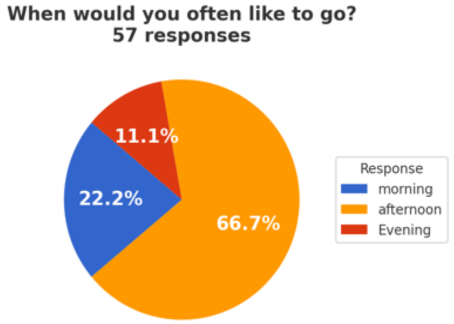

If full assistance is not available, to what extent can you manage daily tasks on your own?
57 responses
I can't manage it on my own and I need full support
It will be better with some support
I will manage it on my own and no support needed
33 (61.1%)
14 (25.9%)
5 (9.3%)
0
10
20
30
Number of Responses

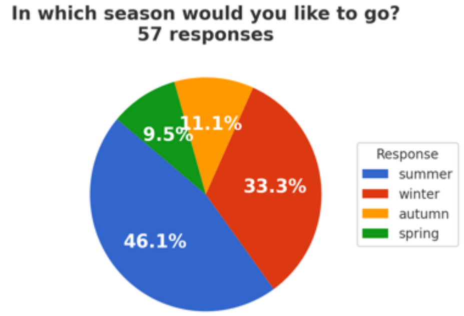

Are you feeling safe in the station?
57 responses
55.6%
29.6%
14.8%
Response
yes
Maybe
Yes
No

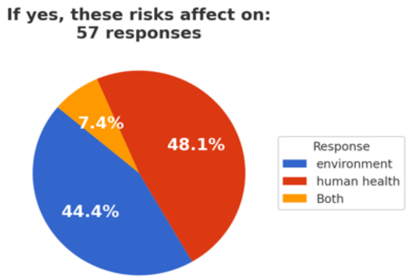

How often do you go there?
57 responses
11.1%
29.6%
59.3%
Response
always
sometimes
rarely

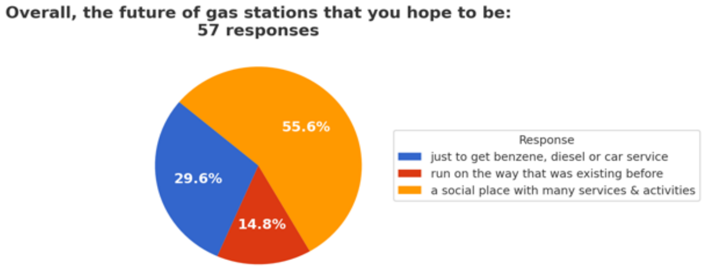












Stage 3: Evaluation of Air Quality:

PFS stations are considered high risk for accidents due to hazardous zones with explosive atmospheres.

Based on the evaluation of health hazards derived from scientific research and literature review, stations were segmented into four zones: Zone 0, Zone 1, Zone 2, and Zone 3, with measurements taken from reference points at varying distances (1) at 25 meters, (2) at 50 meters, (3) at 75 meters, and (4) at 100 meters. These zones can be classified based on the environmental and health risks they pose:

1. ***Zone* 0**: This zone encompasses areas where a flammable atmosphere is continuously present or lingers for extended periods. The risk of explosions is high in these areas, and they are considered the areas most exposed to TVOC.
2. ***Zone* 1**: This is a very unhealthy zone. A flammable atmosphere is likely to occur during normal operations. While the risk is not constant, it is a significant concern for air pollution.
3. ***Zone* 2**: unhealthy zone
4. ***Zone* 3**: Areas in Zone 2 are those where a flammable atmosphere is not likely to occur during standard operations. However, if it does occur, it will only last a short duration.

(Figs. 8-10) shows the relationship between the location of social spaces and the zones in selected PFS.

Fig. 8: Architectural feature for “Wataniya” PFS.

Fig. 9: Architectural feature for “Full Up” PFS.

Fig. 10: Architectural feature for "Chill Out North 90" PFS.

Figs. 8:10: The figure shows the design concept, services, and activities for the study area of PFSs in New Cairo 1-Egypt, Source: Author

Based on the previous information, social interactions and activities appear concentrated in (Zone 2). One petrol filling station, "Wataniya Station," has been selected to measure air quality and TVOC in Zone 2. The aim is to monitor the extent of users' exposure to pollution resulting from PFS. This helps assess this station's environmental and health impacts on the local community and its users.

On Friday, April 21, 2023, notably, one of the busiest days at PFS, air quality and TVOC were assessed using a D9 device (Fig. 11) in the outdoor environment of Zone 1 and Zone 2. These zones are recognized for their significance in social interactions within the petrol station premises. The assessment of air quality in Zone 1 and Zone 2, situated within a Wataniya gas station, yielded the following average results:

Fig. 11:" D9" device measurements at "Wataniya Station."

Stage 4. Analysis.

An air quality assessment in zone 1 and zone 2, inside a “Wataniya gas station, “yielded average results that fell into the “unhealthy “category. It turns out in Table 3: User Awareness Survey Results that an individual in this region is exposed to 0.34 µg/m3 TVOC, equivalent to annually to about 14 µg/m3. By comparing the results due to the World Health Organization (WHO), which recommended an annual air quality benzene exposure limit of 5 µg/m3, the two zones pose significant health risks to their users.

From the previous study for selected PFS, the result of the relationship between land use and degree of risk at zones could be concluded as shown in (Table 4).

Table 4: The relationship between land use and degree of risk at zones, Source: Author

<table>
<tr><th>Zone</th><th>Distance (m)</th><th>Health concern level</th><th></th><th>Common Activity</th><th>Kind of zone</th><th>Target group</th></tr>
<tr><td>Zone 0</td><td>0 – 25 m</td><td>Hazardous</td><td>An area where a mixture of explosive gas is permanently present</td><td>Fueling,</td><td>Service space</td><td>Usually busy by (Petrol filling workers + people to get service)</td></tr>
<tr><td>Zone 1</td><td>25- 50 m</td><td>Very Unhealthy</td><td rowspan="2">An area where a significant amount of VOC emission has existed during regular operation, besides a mixture of explosive gas.</td><td rowspan="2">Banking machines, convenience stores, café, fast food restaurants (KFC, McDonald’s, Wimpy)</td><td></td><td rowspan="2">Usually busy with Visitors (most of them youth and children)</td></tr>
<tr><td>Zone 2</td><td>50 – 75 m</td><td>Unhealthy</td><td>Socializ ing</td></tr>
<tr><td>Zone 3</td><td>75 -100 m</td><td>Moderate</td><td>An area where a medium emission of VOCs has been existing during regular operation</td><td>car washes, car service</td><td>Semi-social space</td><td>Usually a little busy by various ages</td></tr>
</table>

3.2 Discussion

The study results highlight a strong correlation between VOC (Volatile et, al.) concentrations at petrol stations and related health risks, with significant consequences for environmental safety and public health, particularly in areas frequented by station visitors. A typical design trend was noted, where facilities like cafes and seating areas are approximately 25 to 50 meters away from fuel pumps—a distance categorized as "unhealthy" by World Health Organization (WHO) guidelines (Organization, 2024), (Organization, 2021). Previous studies indicate that individuals within this range experience elevated benzene exposure levels, around 9.9 µg/m³ (roughly 3.1 ppb).

Further research reveals that even short, one-minute daily exposures during refueling can substantially increase benzene levels in the bloodstream, posing considerable health risks to nearby residents and frequent visitors or workers since inhalation is the main route of exposure, WHO advises keeping annual benzene levels below 5 µg/m³ to mitigate these health risks.

The trend of petrol filling stations (PFS) evolving into informal social spaces could have long-term impacts on cultural identity and community dynamics. While these areas might foster local street culture and strengthen social bonds, they could also contribute to gradually diluting unique cultural identities. Balancing the role of these social spaces with the preservation of local character poses a complex challenge for urban planning and cultural preservation efforts.

These findings suggest a need for policy measures within urban planning. Authorities may consider regulating the social use of PFS or implementing pollution control technologies to curb VOC emissions. Developing alternative, safe public spaces for social interaction could fulfill community needs while reducing health risks associated with VOC exposure.

4. Results

This study proposes design criteria for petrol filling stations (PFS) that address health and safety concerns related to volatile organic compound (VOC) exposure. By delineating activity areas based on distance from the fuel source and corresponding VOC concentration, this framework offers a structured approach to minimize health risks while fostering the station's role as a social space. The following criteria are structured around four specific distance ranges with varying levels of VOC exposure.

0–25 m: Hazardous Area (VOC levels ~15 μg/m³)

- Restricted Access for Essential Fuel Activities: Given the high VOC concentrations, the 0–25 m range should be strictly limited to essential fuel-related activities, such as fuel dispensing and storage.
- Fuel Storage and Dispensing: Position fuel pumps and underground storage tanks within this area, where exposure to VOCs is unavoidable but essential.
- Controlled Access and Quick Use: Limit exposure duration by encouraging patrons to refuel and depart quickly. This area is unsuitable for lingering or social interactions.
- Safety Signage and Warnings: Prominently display warnings about VOC exposure and safety instructions to minimize time spent in this area.

25–50 m: Very Unhealthy Area (VOC levels ~10 μg/m³)

- Brief-Stay Amenities and Minimal Occupancy: Due to moderate VOC levels, the 25–50 m range should support only brief-use amenities, minimizing patrons' exposure.
- Short-Term Parking and Essential Services: In this range, place quick-access amenities, such as ATMs or vending machines, and short-term parking. Design these spaces for rapid turnover to reduce time spent here.
- Employee Safety Measures: Provide protective measures for employees who occasionally work within this range, such as access to personal protective equipment (PPE) and VOC information.
- Physical Barriers and Green Infrastructure: Employ barriers, such as walls or vegetation, around the perimeter of this range to reduce VOC drift to lower-risk areas.

50–75 m: Unhealthy Area (VOC levels ~7 μg/m³)

- Moderate-Stay Amenities with VOC Control Measures: The 50–75 m range is suitable for brief-to-moderate stays, including activities that support convenience and limited social interaction.
- Convenience Stores and Quick-Stop Cafes: Position small retail outlets, convenience stores, and cafes here, ensuring sufficient ventilation and air filtration to manage indoor VOC levels.
- Limited Social Seating: Provide seating areas for short durations, such as small outdoor seating near cafes, encouraging shorter visits.
- Employee Facilities with VOC Mitigation: Employee rest areas and staff rooms can be located in this range if equipped with robust air filtration systems to minimize exposure.

- Public Health Awareness Signage: Install educational signage to inform patrons about VOC exposure and encourage limited time in this area.

75–100 m: Acceptable Area (VOC levels ~5 µg/m³)

- Primary Social and Recreational Hub: With VOC levels within acceptable limits, the 75–100 m range is ideal for amenities designed for prolonged social interaction.
- Cafes, Restaurants, and Lounges: This area should be filled with cafes, small restaurants, and seating areas, creating a safe environment where patrons can comfortably spend time.
- Community and Recreational Spaces: Establish community-oriented spaces, such as children’s play areas or meeting spots, enhancing the station's social function.
- Extended Parking and Charging Facilities: This area should be used for long-term parking and electric vehicle (EV) charging stations, as customers may need to stay longer.
- Extensive Landscaping and Green Barriers: Incorporate substantial greenery and landscaping elements to enhance the atmosphere and mitigate residual VOC exposure.

5. Conclusions

This study highlights the dual role of petrol filling stations (PFS) as essential urban infrastructure and emerging social spaces, particularly in cities like New Cairo where public gathering areas are limited. While their evolution into informal hubs of social interaction provides opportunities for community engagement, it also introduces significant health risks due to exposure to volatile organic compounds (VOCs). The research demonstrates that proximity to PFS is associated with elevated VOC concentrations, posing both immediate and long-term health hazards, including respiratory issues and increased cancer risks. Moreover, the study reveals a critical gap in public awareness regarding these risks, underscoring the urgent need for targeted health education and intervention.

The findings call for a re-evaluation of the role of PFS in urban planning to ensure they support community well-being without compromising public health. Implementing design interventions, such as creating buffer zones, integrating green infrastructure to mitigate air pollution, and relocating social amenities to safer zones, can help reduce the environmental and health impacts. Additionally, establishing alternative, dedicated public spaces for social interaction can alleviate the reliance on PFS as informal gathering points. Policymakers and urban planners must adopt a balanced approach that prioritizes safety and sustainability while fostering vibrant, inclusive urban environments.

This research provides a foundation for addressing the complexities of designing and managing PFS as multifunctional spaces. Future studies should explore innovative technologies to minimize VOC emissions, assess the cultural implications of transforming PFS into social hubs, and investigate broader strategies for integrating public health considerations into urban design. These efforts are essential to creating safer, healthier, and more sustainable cities that meet the diverse needs of their communities.

Advanced purification technologies, including nano-material-based coatings and VOC absorptive barriers, have proven effective in reducing pollutants at the source, ensuring healthier environments (Smith & Lee, 2023; Wang & Davis, 2024). These innovations align with broader urban planning strategies that incorporate green infrastructure, such as vegetated walls, permeable pavements, and green roofs, to mitigate air pollution, reduce noise, and enhance the livability of PFS (Brown & Green, 2024). Incorporating renewable energy systems, such as solar-powered EV charging stations, can further reduce the environmental footprint of PFS, supporting sustainable development while addressing pressing urbanization challenges (Brown & Green, 2024).

6. Study Limitations

This research, while providing significant insights, is subject to several limitations that should be addressed in future investigations:

1. Generalizability Constraints – Focused primarily on New Cairo, which has distinct urban and socio-economic characteristics, the findings may not be directly applicable to other regions with different urban structures and demographic profiles. Expanding the study to include diverse urban settings would strengthen the generalizability and relevance of the results.

2. Demographic Constraints – The sample size, while appropriate for the number of PFS visitors, is predominantly composed of young adults (74% aged 18–30). This demographic reflects the primary users of PFS as social spaces, yet it limits insights into how older populations perceive and interact with these environments. Future studies should aim to include a more diverse age range to assess broader social dynamics.

3. Temporal Limitation in VOC Exposure Analysis – VOC levels were monitored at specific intervals, not continuously over time, restricting the assessment of long-term health impacts. Future studies should implement longitudinal monitoring to understand better the chronic health risks associated with prolonged VOC exposure, especially considering seasonal variations.

4. Economic Impact Oversight – The primary focus of this study was on the public health implications of PFS, confirming the health risks associated with VOC exposure as highlighted by the results. The economic aspects, such as revenue generation, employment potential, and the economic feasibility of relocating amenities, were not explored. Future research should delve into these economic factors to assess the sustainability and practicality of redeveloping PFS into social hubs.

7. Recommendations

This research proposes a comprehensive approach to mitigate the health and environmental risks of PFS while enhancing their functionality as integral urban spaces. Key recommendations include:

1. Advanced Air Quality Management Systems
   - Deploy IoT-enabled sensors and AI-based monitoring systems to provide real-time data on air quality and VOC levels, enabling targeted interventions.
   - Incorporate nano-material-based air purification technologies and VOC absorptive barriers to reduce harmful emissions at the source.
2. Integration of Green Infrastructure
   - Utilize vegetated walls, green roofs, and permeable pavements to reduce air and noise pollution, enhance aesthetic appeal, and support biodiversity.
   - Implement IoT-based systems for irrigation and maintenance, ensuring sustainable and efficient management of green infrastructure.
3. Public Awareness and Education
   - Launch educational campaigns to inform the public about the health risks associated with VOC exposure, noise, and light pollution at PFS.

- Foster community engagement by involving residents in the planning and design of PFS to address their needs and concerns.

4. Adoption of Sustainable Design Practices

- Integrate renewable energy solutions, such as solar-powered EV charging stations, to minimize the environmental footprint of PFS.
- Use innovative construction materials like self-healing asphalt and carbon-negative concrete to improve infrastructure durability and sustainability.

5. Regulatory Frameworks

- Enforce policies to regulate the proximity of PFS to residential areas and establish strict guidelines for VOC emissions and noise levels.
- Create designated safe zones within PFS, ensuring that high-risk activities are confined to specific areas with robust safety measures.

6. Development of Alternative Social Spaces

- Reduce the reliance on PFS as informal gathering points by creating accessible and multifunctional public spaces that combine leisure, recreation, and community utility with health and environmental considerations.

By combining methodologies such as IoT-based monitoring, nano-material innovations, and sustainable urban design, PFS can transition into spaces that balance utility, health, and community needs. These measures address the dual challenges of public health and social inclusivity, transforming PFS into safe and sustainable urban hubs (Manini et al., 2008; Jones & Patel, 2023). Ultimately, this approach promotes resilience, sustainability, and livability in rapidly urbanizing environments.

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